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Forecasting efficiency of green suppliers by dynamic data envelopment analysis and artificial neural networks

Hadi Shabanpour [a], Saeed Yousefi [a], Reza Farzipoor Saen [b,*]

[a] Young Researchers and Elite Club, Karaj Branch, Islamic Azad University, Karaj, Iran
[b] Department of Industrial Management, Faculty of Management and Accounting, Karaj Branch, Islamic Azad University, P. O. Box: 31485-313, Karaj, Iran

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ABSTRACT

Traditional models of data envelopment analysis (DEA) and dynamic DEA cannot forecast future efficiency of decision making units (DMUs). In other words, all models of DEA and dynamic DEA evaluate and rank DMUs based on past performance. This paper opens a new perspective to realm of DEA as it proposes a transition from previous supervising models to a future planning approach which contains novel contributions. For the first time, artificial neural networks (ANN) are combined with dynamic DEA to forecast future efficiency of DMUs (green suppliers). To this end, firstly, we forecast inputs, outputs, and links of the green suppliers using ANN. Then, the forecasted data derived from ANN are used in dynamic DEA. Dynamic DEA evaluates green suppliers in past, present, and future periods, simultaneously. Our proposed approach has helpful outcomes for decision makers. A case study demonstrates applicability of the proposed approach.

1. Introduction

Previous and even current data envelopment analysis (DEA) models are heavily dependent on historical data (past performance) and do not evaluate prospective efficiencies of decision making units (DMUs). Main objective of this paper is to present a new predictive approach as a transition from traditional supervising methods of efficiency evaluation to a future planning approach. To this end, for the first time, by combining artificial neural network (ANN) and dynamic DEA, green suppliers are evaluated given past, present, and future performances, simultaneously. As a result, future efficiencies of suppliers are forecasted. Note that DMU is an entity that consumes multiple inputs to produce multiple outputs. In this paper, each DMU represents a green supplier.

Selecting the greenest suppliers has become a strategic topic for most manufacturing companies. Normally, primary aim of decision makers is to achieve the best combination of responsiveness and efficiency to succeed in market. Hence, they wish to reduce costs, delivery time, and increase quality of goods and services (Liao and Kao, 2011). However, in recent years, awareness among stakeholders regarding environmental pollution, global concerns, and public pressures has been promoted. Therefore, given scarcity of natural resources, considering environmental and social criteria while evaluating efficiency of suppliers have become unavoidable duty for industries (Govindan et al., 2013). This means that to survive in markets, traditional criteria such as unit cost and geographic proximity are insufficient in green supplier selection problems (Yousefi et al., 2016). Hence, decision makers should consider social and environmental criteria in addition to economic criteria while assessing suppliers (Tavana et al., in press). DEA is one of the popular techniques for selecting suppliers (Stewart, 2010).

DEA, initially, was developed by Charnes et al. (1978). DEA is a technique which evaluates relative efficiency of DMUs and determines efficient and inefficient DMUs. However, there might be ties among efficient DMUs. This reduces discrimination power of DEA. To obviate this issue and rank DMUs, several approaches have been proposed in DEA context. Usage of ideal DMU is one of the DEA approaches for ranking DMUs (Wang et al., 2008). The other approach for ranking efficient DMUs is to use super-efficiency proposed by Andersen and Petersen (1993). Another research stream is cross-efficiency introduced by Sexton et al. (1986). To evaluate DMUs in multiple past periods, for the first time, Sengupta (1995) introduced dynamic DEA given Farrell (1957) structure. Subsequently, to assess DMUs during different periods, Tone and Tsutsui (2010) proposed a dynamic slacks-based measure (DSBM) model using carry-over variables. They classified carry-over

* Corresponding author.
E-mail addresses: hadi.shabanpour@gmail.com (H. Shabanpour), saeedyousefi12@yahoo.com (S. Yousefi), farzipour@yahoo.com (R.F. Saen).

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variables (links) as desirable links, undesirable links, discretionary links, and non-discretionary (fixed) links. Undoubtedly, one of the main weaknesses of conventional models of DEA is that the models evaluate DMUs merely based on historical data of a specific past period. Given fluctuations in performance of DMUs during several periods, considering just a specific past period could be insufficient to evaluate DMUs properly. In dynamic DEA, presented by Tone and Tsutsui (2010), the DMUs' efficiencies are assessed during several past periods. That is why dynamic DEA is more reliable than conventional DEA in case of supplier selection. However, as mentioned earlier, common weakness of all conventional DEA and dynamic DEA models is that they cannot forecast future efficiency of DMUs. In other words, all aforementioned DEA models evaluate efficiency of DMUs in multiple past periods. However, in real world problems, decision makers wish to play role of “preventive controller”. Accordingly, in this paper, for the first time, future efficiencies of DMUs (green suppliers) are forecasted using ANN and dynamic DEA.

Nowadays, ANN has many applications. Clustering (Melchiorre et al., 2008), classification (Zhang, 2000; Krakovsky and Forgac, 2011), and ranking (Krakovsky and Forgac, 2011) are some applications of ANN. The ANN has also been applied to forecast future dataset (Ibiwoye et al., 2012; Nguyen, 2005; Zhang et al., 1999; Lu and Rosenbaum, 2003). This study utilizes ANN along with dynamic DEA to forecast efficiency of DMUs. To this end, we initially forecast inputs, outputs, and links of the DMUs using ANN. We then evaluate the DMUs in different periods by running dynamic DEA. Subsequently, by informing decision makers from future efficiencies of DMUs, we can perform preventive actions. As a result, we can improve efficiency of prospective inefficient DMUs in advance.

The rest of this paper is organized as follows: Literature review is presented in Section 2. In Section 3, proposed method is given. A case study is presented in Section 4. Finally, concluding remarks are discussed in Section 5.

2. Literature review

2.1. Supplier and green supplier evaluation methods

Over past years, DEA has been used to evaluate and select the best suppliers (e.g., Farzipoor Saen, 2008; Noorizadeh et al., 2011; Azadi and Farzipoor Saen, 2012; Mahdiloo et al., 2015; Shabani et al., 2012). To rank suppliers, Farzipoor Saen (2008) proposed an evaluation method based upon super-efficiency analysis. Likewise, Noorizadeh et al. (2011) proposed DEA model for selecting suppliers in presence of dual-role factors, non-discretionary inputs, and weight restrictions. Azadi and Farzipoor Saen (2012) developed a new slacks based measure DEA model to aid managers to select the best suppliers in presence of undesirable outputs and stochastic data. Mahdiloo et al. (2015) extended DEA model to utilize technical, environmental, and eco-efficiency measurements for supplier selection.

Furthermore, Büyüközkan and Çifçi (2011) selected green suppliers using fuzzy analytic hierarchy process (AHP) technique. To assess environmental performance of suppliers, Awasthi et al. (2010) used fuzzy technique for order of preference by similarity to ideal solution (TOPSIS). They suggested three steps; (1) recognition and introduction of environment friendly technologies; (2) assessing environmental performance of suppliers by defining criteria and evaluating suppliers, and (3) running sensitivity analysis to identify role of each factor. Yeh and Chuang (2011) selected green suppliers in electronic industry in Taiwan by running two multi-objective genetic algorithms. To select superior green suppliers, another research stream was proposed by Kuo et al. (2010). They combined ANN and analytic network process (ANP) into DEA.

2.2. Data envelopment analysis (DEA) and dynamic DEA

DEA is an applicable technique to evaluate, compare, and rank relative efficiency of DMUs. This evaluation is done based on ratio of weighted outputs to weighted inputs (Charnes et al., 1978). DEA was extended by Andersen and Petersen (1993) through super-efficiency model for ranking DMUs. Lee and Zhu (2012) introduced a model to evaluate DMUs in presence of zero inputs. Noorizadeh et al. (2013) developed a new cross-efficiency model for ranking DMUs. Using ideal DMU has been another approach for ranking DMUs. Ideal DMU had previously been determined based upon opinions of decision makers. Yousefi et al. (2014) developed a new ideal DMU based on operational results. Another approach is to rank DMUs based on their closeness to efficiency frontier and their distance from deficiency frontier (Wang and Sang Chain, 2009). To rank DMUs, a further stream of research is DEA-discriminant analysis (DEA-DA) technique. DEA-DA can also rank DMUs (Farzipoor Saen, 2013). Stewart (2010) combined goal programming and DEA to introduce benchmarks for inefficient DMUs. He incorporated goals of decision makers in his proposed model. However, Stewart's approach does not consider historical data of DMUs and the goals are set based on subjective judgments of decision makers.

Dynamic DEA was initially introduced by Sengupta (1995) and later it was developed based on studies of Färe and Grosskopf (1996). Tone and Tsutsui (2010) introduced DSBM model to evaluate DMUs during multiple periods. They proposed four types of carry-overs (links) including desirable, undesirable, discretionary, and non-discretionary (fixed) links. Moreover, Tone and Tsutsui (2014) proposed a dynamic DEA model with network structure to merge network slacks-based measure (NSBM) and DSBM models. However, they did not propose any model for assessing and predicting future efficiency of DMUs.

2.3. Artificial neural networks (ANN) and DEA

Neural networks were developed with a simple model of a neuron by McCulloch and Pitts (1943). They showed that human's neural network system can be imitated by a mathematical algorithm. Their idea was the first foundation for creation of ANN (Rumelhart et al., 1986). ANN is a universal non-linear function inspired by human's real neural network system (Zhang, 2000). ANNs are data driven self-adaptive methods which were firstly devised for showing that a neural network can be mimicked by a mathematical algorithm to solve any computational problem (Zhang, 2000). ANNs have been used in many applications. Some of applications include ecology (Gevrey and Worner, 2006; Zhang and Wei, 2009; Zhang, 2011), forecasting (Ibiwoye et al., 2012; Nguyen, 2005; Zhang et al., 1999; Lu and Rosenbaum, 2003), classification (Zhang, 2000; Krakovsky and Forgac, 2011), and clustering (Melchiorre et al., 2008).

Emrouznejad and Shale (2009) measured efficiency of DMUs by combining DEA and ANNs. Desheng et al. (2006) combined DEA and ANN to evaluate efficiency of bank branches in Canada. Using combination of DEA and ANN, Chun Tsai et al. (2009) forecasted unreliable customers who were applying for loans from a financial institution in Taiwan.

Note that efficiency evaluation by previous DEA models is merely based on past performance. This means that classical models of DEA cannot assess future efficiency of DMUs. Hence, this paper suggests a new approach for predicting future efficiency of green suppliers. Authors believe that this paper has significant contributions which are beyond the realm of existing DEA models.